Performance and Economics of the PV Hybrid Power System at Dangling Rope Marina, Utah

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Abstract. The National Park Service has operated a large photovoltaic (PV) hybrid power system at the Dangling Rope Marina since August 1996. Performance and economic analyses for this system based on its first year of operation have been published elsewhere [1,2]. Now, as the system enters its third year of operation, recent changes to the site electrical load and impending additions to the PV array raise new interest in this site as the subject of analysis and evaluation. In 1998, energy conservation measures reduced the site electrical load by 10-12%. At the same time, funding has been allocated to expand the PV array by 40% in 1999. This paper analyzes the effects that these changes will have on the site's fuel use and 20-year life cycle cost.

INTRODUCTION

Dangling Rope Marina is a commercial dock on the north shore of Lake Powell in the Glen Canyon National Recreation Area. Boaters visit the marina year-round to purchase fuel, food, supplies, and ice. Prior to 1996, three diesel generators provided electrical power to the marina's commercial, residential, and maintenance buildings. In the spring of 1996, construction of a large PV hybrid power system was begun on-site by Applied Power Corporation (Lacey, WA). The new power system was completed in August of that year. Cost share for the hybrid power system was divided between the National Park Service, the Utah Department of Natural Resources, Pacificorp and Utah Power and Light, the Department of Energy (including the Federal Energy Management Program and Sandia National Laboratories), ARAMARK Leisure Services, and the Environmental Protection Agency.

Since its commissioning, there has been interest in the performance of this large and notable project from the many participating agencies and others. Following its first operational year, a thorough technical and economic evaluation was performed on the system [1]. This report's findings were that the hybrid system had high reliability and availability, significantly-reduced fuel use and fuel barge deliveries. The annualized cost of delivering power to the marina was reduced by $77k per year. However, the report also stated that the annual site electrical load was 22% greater than anticipated and that conservation measures in addition to those already made by the National Park Service and it concessionaire were recommended to further reduce the load.

In 1998, a new round of energy efficiency measures were completed that effectively reduced the site load by over 10% from previous years. In addition, several of the original cost share participants have agreed to fund an addition to the PV array, increasing its capacity by 40% to a total rating of 160.6 kWdc.

This paper reviews the performance and economics of the hybrid system as it operated in 1996/97. This review is followed by an evaluation of the effects on performance and economics that the present, reduced site load will have. Lastly, it projects performance and life cycle costs for the system that will be in service once the new PV array addition is completed.

THE 1996 PV HYBRID POWER SYSTEM

The Dangling Rope Marina PV hybrid power system consists of a PV array, a battery bank, an inverter/rectifier, and two propane-fueled generators. The array has 384 ASE 300-DG/50 modules with a nominal array dc rating of 115 kW. The battery bank uses 792 C&D model 6-C125-25 cells arranged in 40 steel trays with a total capacity of 2.4 MWh at the nominal 396 VDU operating voltage. The inverter/rectifier was built by Kennetech Windpower (now Trace Technologies). It uses the model HY-250 Power Processing Unit. In the inverting mode it produces 480 Vac, 3 phase 60 Hz power with a continuous rating of 250 kVA. There are two Caterpillar model 3408 propane-fueled generators. Each generator is rated at 250 kVA, 3 phase, 480 Vac.

1996/97 Performance and Economics

In the period from September 1996 through August 1997, the marina electrical load was 438.3 MWh. Approximately two-thirds of all electrical generation was provided by the propane generators and one-third by the PV array. Generators ran a total of 2516 hours producing 345.4 MWh of electricity while consuming 54,442 gallons of fuel. The PV array produced 180.5 MWh (dc).

Based on system purchase price, operational data, maintenance records, fuel price, and maintenance schedules, a 20-year life cycle cost (LCC) analysis was calculated for the hybrid system. Similar LCC calculations were prepared for generator-only (both diesel and propane) power systems. Table 1 presents a LCC comparison for the three alternative power systems. In the table, Base96-d and Base96-p refer to diesel and propane generator-only power systems, alternatively. Hybrid96 refers to the hybrid system as installed.

As shown in Table 1, the hybrid was projected to have a 20-year LCC less than the propane-fueled generator option and more than a diesel-fueled generator option. In

either case, the hybrid was projected to save half the fuel and over one-third the maintenance costs needed by the generator-only alternatives.

TABLE 1. 20-Year Life Cycle Cost Comparison: Three 1996 System Alternatives

	Base96-d	Base96-p	Hybrid96
Initial Investment	$86,868	$86,868	$1,3000,000
Annual and Non-Annual Recurring Costs	$393,699	$393,699	$190,484
Energy –Related Costs	$2,066,865	$2,33,602	$1,198,305
Capital Replacements	$164,039	$164,039	$200,731
Net Present Value	$2,711,472	$2,981,209	$2,889,520

1998: EFFECTS OF REDUCING THE SITE LOAD

Since the 1996 installation of the Dangling Rope Marina hybrid power system, the National Park Service and its concessionaire, ARAMARK, have continued to work to improve its performance. Both organizations have recognized that reduction in the electrical load is the key step to reducing generator run time and thus controlling energy-related costs.

In 1998, two actions were completed that effectively reduced the site electrical load by more than 10%. The first was the completion of a program begun in 1996 with the installation of the hybrid system. At that time, thirty-six propane-fueled space heaters, stoves, water heaters, and dryers were purchased to replace existing electrical appliances. In 1998, the last of these replacement appliances was installed. The second action completed in 1998 was the replacement by the concessionaire, ARAMARK, of an oversized 65 kW heat pump with four, smaller and more efficient 12 kW units. These heat pumps provide heating and cooling to the marina store and other buildings on the dock. The four units are now staged to provide heating and cooling only where needed, reducing wasted energy.

The direct result of the reduction in load should be reduced generator run time, fuel use, and associated engine maintenance costs. Serving the reduced site load, the generators are projected to run 2265 hours per annum in 1998/99, down from 2516 hours in 1996/97. This will save 5440 gallons of propane per year. With the reduced

requirements for fuel and maintenance, a reduction of 10% in the site load will yield a reduction in the system net present value from $2.89M to $2.78M. This is a savings of more than $100k, or about 4% of the total. Presentation of the complete LCC comparison for this case is given in Table 2 in the next section below.

1999: EFFECTS OF INCREASING ARRAY CAPACITY

Another major change in the Dangling Rope Marina hybrid power was begun in August 1998. At that time, the cost share needed for the purchase of an additional 45.6 kW dc of PV was finalized. The cost share participants will be the Department of Energy (State Energy Program Award), ARAMARK Leisure Services, and the Utah Department of Natural Resources. The cost for the increased capacity will be $306k, or $6.7/W dc installed. Installation of the new PV is scheduled for spring 1999.

The addition of 45.6 kW of PV to the existing 115 kW array represents an increase of approximately 40%. Evaluating the payback for this additional PV can be performed using several methods. The first and simplest method is to calculate payback based on the value of the energy that will be produced by the new PV. The annualized cost of electrical energy for the hybrid power system calculated in [1] was $0.49/kWh. Based on the recorded kWh/kW installed for the initial PV array, the array addition is projected to produce about 70.4 MWh of electricity per year, worth about $34.5k. Based on the purchase price of $306k, this results in a simple payback of less than nine years.

A second and more conventional approach to the evaluation of the costs of the new PV addition is to calculate the 20-year LCC for the entire system based on its initial purchase price in year 0 followed by the capital outlay for the new PV addition in year 3. This approach is presented in Table 2. In Table 2, the column *Original Hybrid96* reproduces for comparison the LCC figures for the hybrid as installed in 1996 (from Table 1). The column *Revised Hybrid96* maintains the 1996 system specifications but models the LCC based on the new site load observed in 1998. Lastly, the column *New Hybrid98* models the LCC for the system using the 1998 observed site load and includes the purchase of 45.6 kW of PV in year 3 of operation.

TABLE 2. 20-Year Hybrid System Life Cycle Cost Comparison: Revised 1998

	Original Hybrid96	Revised Hybrid96	New Hybrid98
Initial Investment	$1,300,000	$1,300,000	$1,300,000
Annual and Non-Annual Recurring Costs	$190,484	$186,079	$150,980
Energy-Related Costs	$1,198,305	$1,089,535	$862,194
Capital Replacements	$200,731	$200,731	$471,980
Net Present Value	$2,889,520	$2,776,345	$2,785,154

Calculated this way, the cost of the new PV addition is paid back after 20 years of operation. That is, the 20-year LCC values of the hybrid power system with and without the additional PV are virtually the same. Even without a favorable monetary payback, however, many favorable benefits will accrue from the installation of additional PV. With the additional PV, the site will consume 11,000 gallons less propane per year and require about five fewer fuel barge deliveries. Also, the number of oil changes required by the engines each year will be reduced from nine to seven. Lastly, the time between engine overhauls will extend from every four years to every six years. In practical terms, these operational benefits mean less required maintenance will be needed throughout the seventeen remaining years of system service life. And finally, the reduced fuel use will also result in CO_2 emissions being cut by about 1,000 tons annually.

CONCLUSIONS

From the beginning, the Dangling Rope Marina PV hybrid power system project has been a collaboration among several Federal agencies, the National Labs, the State of Utah, and private industry. All of the participants have shared the common goals of promoting renewable energy and providing reliable power to the marina's visitors and residents.

As originally configured, the 20-year LCC of the hybrid power system at Dangling Rope Marina was less than for a conventional propane-fueled generator system and more than for a diesel-fueled system. In 1998, energy efficiency improvements were taken that will result in reduced site load, generator run time, fuel consumption, and

maintenance costs. These improvements in energy efficiency are calculated to lower the LCC for the hybrid system by more that $100k. Lastly, plans call for the PV array to be expanded by 40% in 1999. This expansion of the array will have operational benefits for the life of the system including less fuel consumption, fuel barge deliveries, and regular maintenance for the generators.

The economics of PV hybrid power systems are competitive today with full-time fossil-fuel burning generators in off-grid applications. The hybrid power system at Dangling Rope Marina is serving as a model and example of a practical renewable energy power system to the National Park Service and other Federal agencies.

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REFERENCES

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